# Weather and the Transmission of Bacillary Dysentery in Jinan, Northern China: A Time-Series Analysis

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## SYNOPSIS

**Objectives.** This article aims to quantify the relationship between weather variations and bacillary dysentery in Jinan, a city in northern China with a temperate climate, to reach a better understanding of the effect of weather variations on enteric infections.

**Methods.** The weather variables and number of cases of bacillary dysentery during the period 1987–2000 has been studied on a monthly basis. The Spearman correlation between each weather variable and dysentery cases was conducted. Seasonal autoregressive integrated moving average (SARIMA) models were used to perform the regression analyses.

**Results.** Maximum temperature (one-month lag), minimum temperature (one-month lag), rainfall (one-month lag), relative humidity (without lag), and air pressure (one-month lag) were all significantly correlated with the number of dysentery cases in Jinan. After controlling for the seasonality, lag time, and long-term trend, the SARIMA model suggested that a 1°C rise in maximum temperature might relate to more than 10% (95% confidence interval 10.19, 12.69) increase in the cases of bacillary dysentery in this city.

**Conclusions.** Weather variations have already affected the transmission of bacillary dysentery in China. Temperatures could be used as a predictor of the number of dysentery cases in a temperate city in northern China. Public health interventions should be undertaken at this stage to adapt and mitigate the possible consequences of climate change in the future.

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Enteric infections are still a public health problem in both developed and developing countries.[1] For example, diarrhea is responsible for 2.5 million deaths per year in some developing countries.[2] Dysentery, one of the major diarrheal diseases in China, has caused more than 300 deaths per year in the last decade.[3] The bacteria are transmitted by the fecal-oral route via contaminated water, food, or person-to-person contact.[4] The pathways of the impact of weather variables on the transmission of enteric infection could be various, both indirectly and directly. Temperatures may directly influence the rate of replication of pathogens and the survival of pathogens in the environment. Additionally, weather variations may affect human behavior, including eating habits, which influence the transmission of enteric infection indirectly.

The impact of climate variations on some enteric infections, e.g., cholera and salmonellosis, has been studied.[5,6] However, the relationship between dysentery and weather variables has not been examined to date. Bacillary dysentery commonly occurs in summer, which suggests a potential association with weather conditions. To examine the relationship between weather variables and bacillary dysentery, this study quantifies the association between the number of dysentery cases and weather variables—including maximum and minimum temperature, relative humidity, rainfall, and air pressure—in Jinan, China, using time-series analysis for existing disease surveillance data, with the consideration of lagged effects, autocorrelation, and seasonal fluctuation of the number of dysentery cases.

## METHODS

### Background

Located in eastern China, Jinan is the capital city of Shandong Province. The population in 2004 was about 3.3 million, of which about 12% was younger than age 14 and about 8% was 65 years of age and older; the gender ratio was approximately 102 (male/female).[7] Jinan has a temperate weather with dry winters and wet, hot summers. The annual mean temperature is about 15°C. Economic development in Jinan urban areas was rather even without significant difference between sub-areas in terms of socioeconomic status within the study period.

### Data collection

***Surveillance data.*** Bacillary dysentery has been a legally notifiable disease in China since the 1960s. In this study, all bacillary dysentery cases diagnosed by authorized hospitals in the target city (urban area) and reported to the local authority are included. Monthly notified cases of bacillary dysentery in Jinan were collected from the Jinan Municipal Centres for Diseases Prevention and Control (CDC), the official organization providing notifiable disease data. In addition to passive surveillance of infectious diseases, the local CDC conducted active surveillance regularly to reduce the rate of misreport and underreporting.

***Meteorological data.*** Daily weather data for Jinan were extracted from the China Meteorological Administration Climatic Dataset Centre. The weather variables included daily maximum and minimum temperature, relative humidity, rainfall, and air pressure as measured in the sole weather station in Jinan.

### Study period

Although the record of notified dysentery cases is from the 1960s, the study period is from 1987 to 2000. This is because the proportion of underreporting and misreporting could have been inconsistent in 1967–1974 due to political reasons in China and because the size of administrative areas in Jinan changed repeatedly before 1987.

### Data analyses

***Correlation analyses.*** Spearman correlation between the number of cases and each weather variable was conducted with consideration of lag effects.

***Regression analyses.*** The seasonal autoregressive integrated moving average (SARIMA) model was used to estimate the parameters of the regression model. SARIMA is an approach to handle time-series modeling and forecasting based on the landmark work of Box and Jenkins, which takes into account the impact of seasonality and autocorrelations.[6] A SARIMA model can be described as ARIMA (p,d,q) multiplied by (P,D,Q), where the terms p,d,q represent ordinary components, while P,D,Q represent seasonal components. These terms were determined by the autocorrelation function (ACF) and partial autocorrelation function (PACF).[7] The theory and application of the models have been described in many papers and books.[8–11] The Aikake Information Criterion (AIC) was used to compare the model fits, and the diagnostic of the residuals was performed by scatter plotting and the figures of ACF and PACF.[9]

All analyses were performed using SPSS 11.5[12] with a significant level of $p=0.05$.

## RESULTS

### Description of bacillary dysentery in Jinan, 1987–2000

In total, there were 60,905 bacillary dysentery cases in Jinan during the study period with a mean monthly incidence rate of 7.2 per 100,000. Cases were from all age groups, with most cases from children younger than age 4 (approximately 25%) and young adults between 20 and 40 years of age (approximately 33%). The time series of the number of cases and the weather variables is shown in Figure 1. A clear seasonal pattern has been observed, with more cases occurring in summer and fall.

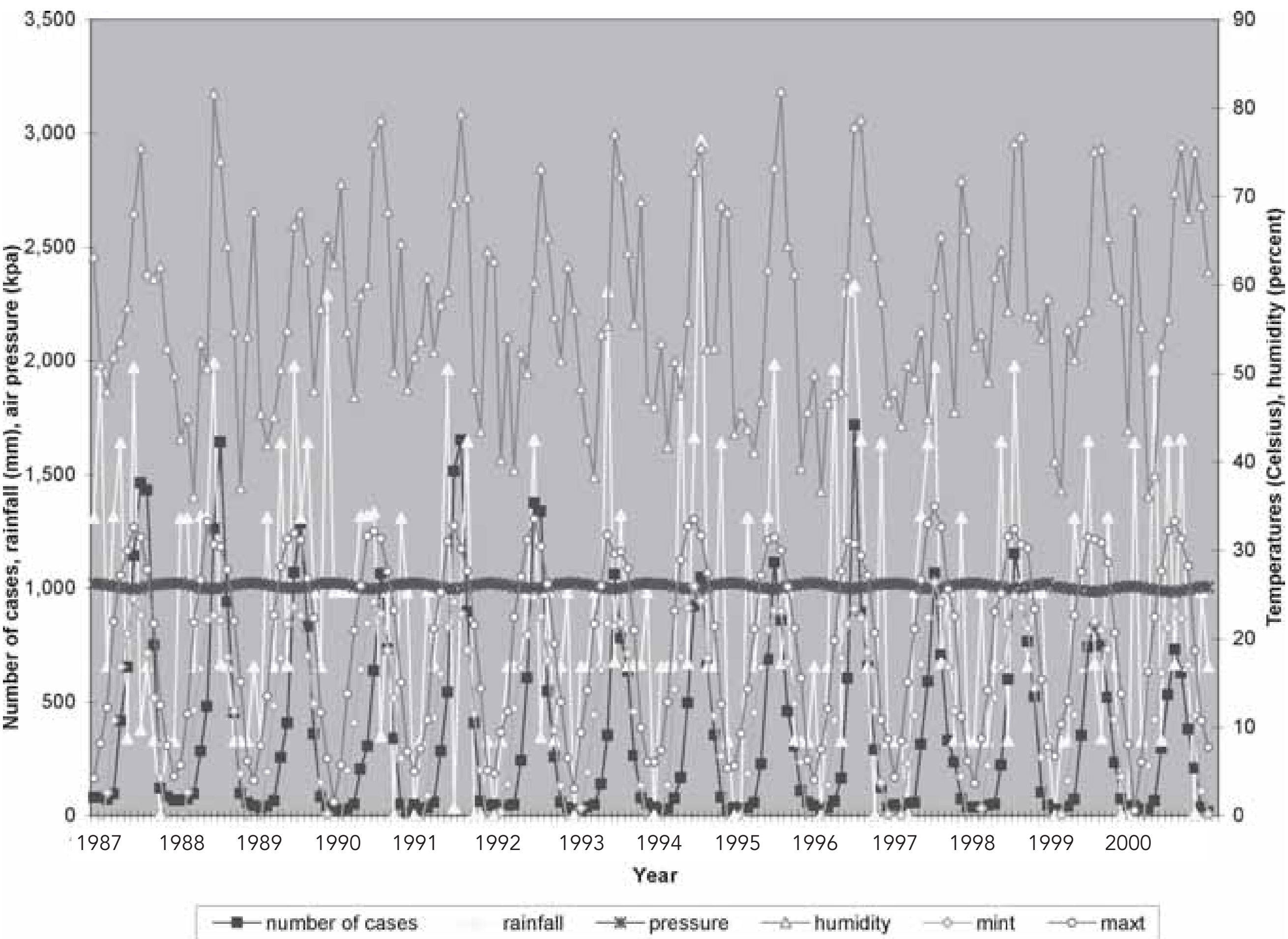
### Correlations

***Spearman correlation between the number of cases of bacillary dysentery and each weather variable.*** Spearman correlation coefficients between each weather variable and monthly number of cases of bacillary dysentery at various time-lag values are summarized in Table 1. The results suggest that maximum temperature, minimum temperature, rainfall, and relative humidity were positively related, while air pressure was negatively related with the number of dysentery cases in Jinan during the study period.

### SARIMA regression

All the weather variables significantly related to the number of cases and the socioeconomic indicators are included in the regression models. Due to the high correlation between maximum and minimum temperatures ($r$=0.985), two separated models including maximum and minimum temperature were set up respectively for consideration of multicollinearity. The model showing minimum temperatures is not included

**Figure 1. Sequence of weather variables and bacillary dysentery in Jinan, Northern China, 1987–2000**




Mint = minimum temperature

Maxt = maximum temperature

**Table 1. Correlation coefficients and *p*-values between bacillary dysentery and weather variables in Jinan, Northern China**

| | *Coefficient (95% CI)* | *P-value* | *Lag time* |
|---|---|---|---|
| Mean maximum temperature (°C) | 0.91 (0.88, 0.94) | <0.0001 | 1 month |
| Mean minimum temperature (°C) | 0.90 (0.88, 0.92) | <0.0001 | 1 month |
| Total rainfall (mm) | 0.45 (0.39, 0.51) | <0.0001 | 1 month |
| Mean humidity (percent) | 0.57 (0.52, 0.62) | <0.0001 | 0 |
| Mean air pressure (percent) | −0.81 (−0.89, −0.72) | <0.0001 | 1 month |

CI = confidence interval

because it is very similar to the model displaying maximum temperatures.

The parameters of the SARIMA regression model including maximum temperature are shown in Table 2.

**Table 2. Parameters estimated by the SARIMA model with maximum temperature**

| | *B* | *Standard error* | *T* | *P-value* |
|---|---|---|---|---|
| AR2 | −0.2418 | 0.0797 | −3.032 | 0.003 |
| SMA1 | −0.3364 | 0.0797 | −4.218 | 0.000 |
| Lag1 max temp | 0.1144 | 0.0064 | 17.861 | 0.000 |
| Constant | −0.0120 | 0.0322 | −0.372 | 0.710 |

SARIMA = seasonal autoregressive integrated moving average

AR2 = order-2 autoregression

SMA1 = 1-order seasonal moving average of cases

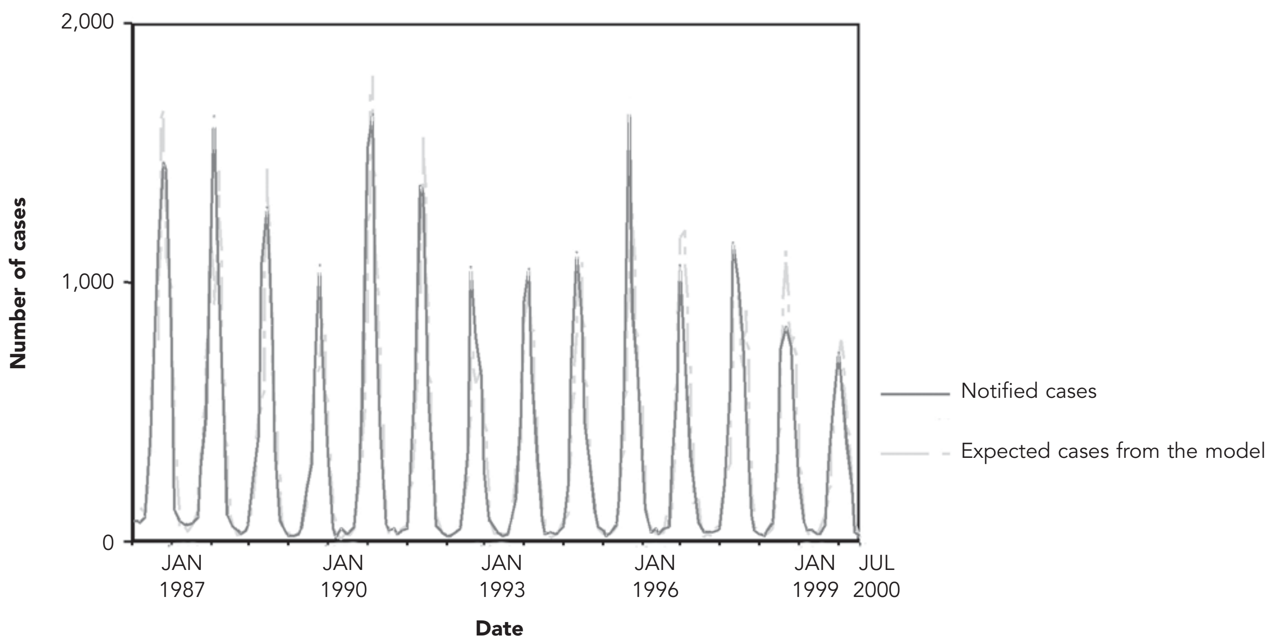
lag1 max temp = maximum temperature occurring one month prior

The significant parameters in the model include an order-2 autoregression of the number of dysentery cases, 1-order seasonal moving average, and maximum temperature one month prior (Table 2). It suggests that a 1°C rise in maximum temperature is related to an 11.4% (95% confidence interval 10.19, 12.69) increase in the cases of bacillary dysentery. The goodness of fit is illustrated in Figure 2 with AIC=195. The diagnostic of the residuals demonstrated randomly distributed residuals and no autocorrelation among them (Figure 3).

## DISCUSSION

This is the first systematic epidemiological study to examine the association between weather variables and dysentery in China. This study also examined the role of socioeconomic factors in dysentery transmission,

**Figure 2. Notified cases vs. model fit cases of bacillary dysentery in Jinan, Northern China, 1987–2000**



which is unique in similar studies. The results from this study indicate that only ambient temperatures (both maximum and minimum temperatures) have significantly affected the transmission of dysentery in Jinan, although other weather variables including rainfall, relative humidity, and air pressure might also relate with the number of dysentery cases.

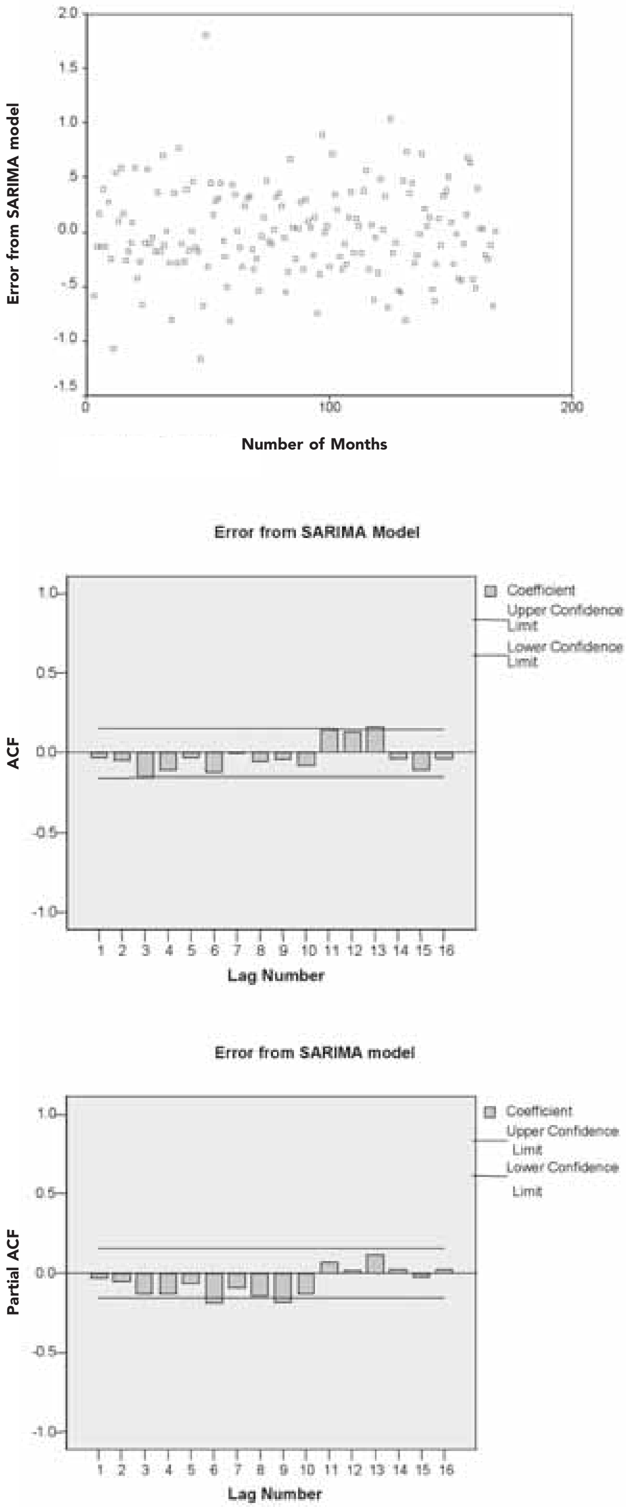
The association between climate variations and enteric infection has attracted less attention compared with the studies on vector-borne diseases, e.g., malaria, dengue, and Ross River virus infection.[13–15] Some recently published articles suggest that over a certain threshold, there was a linear relationship between temperature and salmonellosis transmission in Europe and Australia.[5,16] Similar positive correlation between temperatures and other enteric infection (e.g., campylobacter infection and cholera) has also been detected.[5,15] However, there has been no report on the effect of climate variations on dysentery cases so far.

All published studies indicate a lag effect of temperature on some enteric infection with the range from 0 to 14 weeks.[5,16–18] In our study, we found a one-month lagged positive effect of temperatures on dysentery cases. The regression model suggests that temperatures have already affected the transmission of bacillary dysentery in Jinan, and a 1°C increase in maximum temperature may cause an increase of more than 10% of cases in the future. Temperatures could be used as an early forecasting factor in the public health practice in Jinan.

Other weather variables, such as rainfall, humidity, and air pressure, may also contribute to the transmission of enteric infection. However, their associations are far from clear. Some studies claim that rainfall does not affect the transmission of enteric infection,[5,16] while other studies obtained inconsistent results.[18] In this study, although there was a significantly positive association in the correlation analysis, rainfall was not included in the regression model. Relative humidity and air pressure were significantly correlated with the number of bacillary dysentery but not significantly included in the regression model. Indeed, the impact of weather variables is synthesized rather than independent. More studies in other areas are needed to understand the association between these weather variables and enteric infection.

Statistical issues need to be addressed in time-series data analysis, including the control of secular trend, seasonality, and autocorrelation. Regression models including Poisson regression, multiple linear regression, and SARIMA models have been used to quantify the relationship between weather variables and infectious diseases.[5,16,18,19–21] However, there are few

**Figure 3. Plotting of the residuals of the SARIMA model**




SARIMA = seasonal autoregressive integrated moving average

ACF = auto correlation function

applications of the SARIMA model in the study on the effect of climate variations on enteric infection.

The SARIMA model has its advantages in time-series analysis. The secular trend, seasonal variation, and autocorrelation could all be easily controlled by difference, autoregression, moving average, and seasonal functions without performing complicated transformation or using extra surrogate variables.[9] The SARIMA model developed in this study shows an excellent goodness of fit, which indicates that it could be an appropriate statistical model to quantify the relationship between climate variations and enteric infection.

The quality and availability of data is another important issue in studying the association between weather variables and infectious diseases, especially for enteric infection. For one, underreporting of enteric infection is inevitable. The influence of underreporting is assumed consistent during the study period, according to the report from internal data audit of Jinan Municipal CDC.[22] Secondly, onset dates rather than notified dates of diseases could be more suitable for such analysis, which may result in a better estimation of the lagged effects. Thirdly, weekly data may bring more accurate estimation of the effects than monthly data. However, only monthly surveillance data were available for this study. Obviously, the improvement of disease surveillance systems and health information sharing need to be addressed, particularly in developing countries.

## CONCLUSION

Recently, increases in temperature have been observed in most parts of China, with an increasing warming trend from southern to northern China.[23] With a population of 3 million in Jinan, global warming and irregular weather events may have a significant impact on the transmission of infectious diseases, including dysentery. Therefore, planning for relevant response mechanisms, including public health intervention measurements, should be undertaken at this stage to adapt and mitigate the possible consequences of weather change.

## REFERENCES

1. World Health Organization. Food safety and foodborne illness [cited 2005 Aug 31]. Available from: URL: http://www.who.int/mediacentre/factsheets/fs237/en
2. Kosek M, Bern C, Guerrant RL. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. Bull World Health Organ 2003;81:197-204.
3. Ministry of Health China. MOH news [cited 2005 Sep 1]. Available from: URL: http://www.moh.gov.cn/public
4. Niyogi SK. Shigellosis. J Microbiol 2005;43:133-43.
5. Koelle K, Rodo X, Pascual M, Yunus M, Mostafa G. Refractory periods and weather forcing in cholera dynamics. Nature 2005;436:696-700.
6. Kovats RS, Edwards SJ, Hajat S, Armstrong BG, Ebi KL, Menne B. The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. Epidemiol Infect 2004;132:443-53.
7. Jinan Statistical Bureau. Report of the 4th population census in Jinan [cited 2007 Jun 17]. Available from: URL: http://www.jinan.gov.cn/col639/col678/jnnj/2002/tz/2.htm
8. Box GE, Jenkins GM. Time series analysis: forecasting and control. Revised ed. San Francisco: Holden-Day; 1976.
9. Shumway RH, Stoffer DS. Time series analysis and its applications: with R examples. New York: Springer; 2000.
10. Tobias A, Saez M. Time-series regression models to study the short-term effects of environmental factors on health [cited 2004 May 3]. Available from: URL: http://www3.udg.edu/fcee/economia/n11.pdf
11. Brockwell PJ, Davis RA. Time series: theory and methods. New York: Springer; 1991.
12. SPSS Inc. SPSS for Windows: Release 11.5.1. Chicago: SPSS Inc.; 2002.
13. Thomson MC, Mason SJ, Phindela T, Connor SJ. Use of rainfall and sea surface temperature monitoring for malaria early warning in Botswana. Am J Trop Med Hyg 2005;73:214-21.
14. Thammapalo S, Chongsuwiwatwong V, McNeil D, Geater A. The climatic factors influencing the occurrence of dengue hemorrhagic fever in Thailand. Southeast Asian J Trop Med Public Health 2005;36:191-6.
15. Gatton ML, Kay BH, Ryan PA. Environmental predictors of Ross River virus disease outbreaks in Queensland, Australia. Am J Trop Med Hyg 2005;72:792-9.
16. D'Souza RM, Becker NG, Hall G, Moodie KB. Does ambient temperature affect foodborne disease? Epidemiology 2004;15:86-92.
17. Tam CC, Rodrigues LC, O'Brien SJ, Hajat S. Temperature dependence of reported Campylobacter infection in England, 1989–1999. Epidemiol Infect 2006;134:119-25.
18. Singh RB, Hales S, de Wet N, Raj R, Hearnden M, Weinstein P. The influence of weather variation and change on diarrheal disease in the Pacific Islands. Environ Health Perspect 2001;109:155-9.
19. Checkley W, Epstein LD, Gilman RH, Figueroa D, Cama RI, Patz JA, et al. Effect of El Nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. Lancet 2000;355:442-50.
20. Bi P, Wu X, Zhang F, Parton KA, Tong S. Seasonal rainfall variability, the incidence of hemorrhagic fever with renal syndrome, and prediction of the disease in low-lying areas of China. Am J Epidemiol 1998;148:276-81.
21. Tong S, Hu W, McMichael AJ. Weather variability and Ross River virus transmission in Townsville Region, Australia, 1985–1996. Trop Med Int Health 2004;9:298-304.
22. Jinan Municipal Centre for Disease Prevention and Control. Surveillance data for national notified infectious diseases. 2001.
23. China Climate Change Info-Net [cited 2007 Jul 30]. Available from: URL: http://www.ccchina.gov.cn/en